Can echocardiographic assessment of interatrial septum shape and motion improve the accuracy of the BLUE protocol?

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ABSTRACT

Acute respiratory failure is one of the most challenging critical conditions due to a wide variety of differential diagnosis. Bedside lung ultrasound in emergency (BLUE) protocol allows accurate differentiation between the most common underlying causes of acute respiratory failure in up to 90% of the cases. The assessment of left atrial pressure affecting left ventricular filling is essential in critically ill patients guiding volume substitution, optimization of left ventricular function and prevention of pulmonary congestion, thus ensuring haemodynamic stability. A simple, non-invasive method of left atrial pressure evaluation is the echocardiographic assessment of interatrial septum shape and motion, which is affected by interatrial pressure gradient. Aiming to improve the accuracy of the BLUE protocol, we propose the simple, non-invasive echocardiographic assessment of interatrial septum shape and motion as an upgrade, providing additional information of the loading of left and right atrium thus distinguishing the most common causes of acute respiratory failure.

Key words: lung ultrasound, BLUE protocol, interatrial septum, echocardiography

INTRODUCTION

Lung ultrasound (LUS) is a simple, non-invasive, easily repeatable and reproducible bedside diagnostic and monitoring tool, providing real-time dynamic images (1). Compared to conventional thoracic imaging modalities (X ray, CT scan), it is free of radiation hazards and does not require transportation of the unstable patient outside the Intensive Care Unit (ICU) (2). In certain pathologies found in ICU (atelectasis, pneumothorax, pneumonia or acute respiratory distress), LUS has been shown to be more accurate than Chest X-ray, due to the imaging method characteristics itself and suboptimal image quality in supine position of critically ill patients (3, 4). Skills needed for the basic LUS assessment can easily be acquired (5, 6) and internationally accepted guidelines are now available to assist clinicians with adopting LUS in daily practice (3).

Acute respiratory failure (ARF) is one of the most common and challenging critical conditions presenting to the emergency department or ICU demanding the establishment of the accurate diagnosis in the shortest time possible (7). The variety of differential diagnoses in ARF has led to the development of bedside lung ultrasound in emergency (BLUE) protocol as an extension of the clinical examination, reducing the time needed to diagnosis and directing early therapeutic measures (8). BLUE protocol consists of LUS and venous ultrasound, which enable differentiation between lung oedema, pneumonia, pulmonary embolism, acute exacerbation of asthma/chronic obstructive pulmonary disease and pneumothorax in up to 90% of the cases (9).

BASICS OF LUS

Contrary to the traditional belief that ultrasound does not provide the insight into the lung pathology due to high gas content, clinical studies in the past 20 years have proven LUS to be a useful tool in different specialties (10). Lung ultrasound is typically performed by a convex probe (e.g. abdominal, cardiac, microconvex probe) with scanning of the three standard points on each side, the upper BLUE point, lower BLUE point and postero-lateral alveolar or pleural syndrome (PLAPS) point (11). The easiest way to recognize the correct landmarks for probe positioning is by placing both hands on the patient’s chest. The upper hand should lie just beneath the clavicle with fingers touching the midline and the lower hand below the upper one (Figure 1a). The upper BLUE point is in the middle of the upper hand, while the lower BLUE point is in the middle of the lower palm (Figure 1a). The third point, the PLAPS point, is achieved by the intersection of two lines, a horizontal line running posteriorly from the lower BLUE point and a vertical one presented by the posterior axillary line (Figure 1b). The anterior points of the chest are scanned first, followed by the PLAPS point examination. According to the rules of gravity, air gathes in the upper parts of the lung while fluid accumulates in the basal parts, therefore pleural effusions and lung consolidations are mainly found in PLAPS points (12).

Ultrasound image is formed from the
management of ARF as most of the cardiorespiratory disorders are superficial and affect the area in close proximity to the pleural line (10). The interpretation of LUS is based on the recognition of 10 elementary signs, which present non-anatomical images (artefacts) as well as anatomical visualisation of the pleural space and lung parenchyma in the presence of effusion and consolidation (14). With recognition of these basic LUS signs, distinction between normal lung surface (bat sign, A-lines and lung sliding), interstitial syndrome (B-lines), pneumothorax (stratosphere sign and the lung point), pleural effusions (quad and sinusoid sign) and lung consolidations (fractal sign and tissue-like sign) can be made (15). Description of the LUS signs is presented in Table 1, while a detailed explanation with corresponding images can be found in the original article by Lichtenstein et al. (8).

**BLUE PROTOCOL**

The principle of the BLUE protocol is division of LUS findings into the following profiles: the A profile associated with anterior lung sliding and A-lines, A’ profile with anterior A-lines but without lung-sliding, B profile with anterior lung sliding and B-lines, B’ with anterior B lines without lung sliding, C profile with anterior lung consolidation and A/B profile as a combination of A and B profiles in the lungs (8) (Figure 2).

BLUE protocol starts with determining the pleural line sliding. If the lung sliding is present, we move to the left side of the scheme and anterior LUS points are checked for the A- or B-lines. In case of B-lines, the B profile is found indicating pulmonary oedema, whereas A-lines in the anterior point warrant further differential diagnosis of A profile between pulmonary embolism, pneumonia or acute exacerbation of asthma/COPD. Ultrasound examination of deep leg veins is performed in order to exclude deep vein thrombosis (DVT). When the examination is positive, pulmonary embolism is the most likely diagnosis. When DVT is excluded, PLAPS points are checked for the signs of lung consolidation or effusion. A profile plus positive PLAPS speaks for pneumonia, whereas A profile and negative PLAPS speak for acute exacerbation of asthma/ COPD. If the lung sliding is absent, we move to the right side of the scheme. In case of B-lines the profile is called B’, suggesting pneumonia. The presence of A-lines, however, demands the search of the lung point to establish the final diagnosis of pneumothorax. If the lung point is not found, other diagnostic modalities should be explored. If the A/B profile or C profile is found in the anterior LUS points, no matter the presence or absence of lung sliding, pneumonia is the most likely cause of ARF (8).

**ASSESSMENT OF INTERATRIAL SEP-TUM SHAPE AND MOTION**

The assessment of left atrial pressure (LAP) affecting left ventricular filling is essential in critically ill patients guiding volume substitution, optimization of left ventricular function and prevention of pulmonary congestion, thus ensuring haemodynamic stability (16). LAP is most commonly assessed by measurement of pulmonary artery wedge pressure (PAWP), obtained by wedging a pulmonary catheter with an inflated balloon into a small pulmonary arterial branch (17). Due to the invasiveness of the procedure, PAWP measurement has limited utility. Non-invasive estimation of LAP is provided by echocardiography, where E/e’ ratio, obtained from mitral inflow Doppler and mitral annulus tissue velocities, correlate well with PAWP (17,18). This correlation is, however, poor in mechanically ventilated and anesthetized patients (19). Furthermore, with limited time available in the emergency setting, a precise echocardiographic examination of diastolic function is inconvenient. LUS in the BLUE protocol allows estimation of extravascular lung water, but is of limited usefulness in prediction of PAWP (14). Therefore, search for new methods of LAP estimation have emerged.

**Table 1. Description of the basic lung ultrasound signs.**

<table>
<thead>
<tr>
<th>Lung ultrasound sign</th>
<th>Description</th>
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<tbody>
<tr>
<td>bat sign</td>
<td>hyperechoic pleural line between two adjacent ribs with posterior acoustic shadowing, where the pleural line represents the belly of the bat and the ribs its wings</td>
</tr>
<tr>
<td>lung sliding</td>
<td>the movement of the pleura while breathing, registered on M-mode as the seashore sign (straight lines presenting the static chest wall and curved lines presenting the lung surface)</td>
</tr>
<tr>
<td>A-lines</td>
<td>horizontal hyperechoic artefacts, extending to the bottom of the screen with a slowly diminishing signal, reflecting the reverberations of the ultrasound wave between the pleura and the probe</td>
</tr>
<tr>
<td>B-lines</td>
<td>hyperechoic, well-defined, comet-tail artefacts, arising from the pleural line, moving along with the lung sliding, extending to the bottom of the screen and erasing A-lines</td>
</tr>
<tr>
<td>stratosphere sign</td>
<td>M-mode through the lung surface reveals a stratified pattern due to absence of lung sliding in case of pneumothorax</td>
</tr>
<tr>
<td>lung sign</td>
<td>the point where motionless pleura in case of pneumothorax and normal normal lung surface meet</td>
</tr>
<tr>
<td>quad sign</td>
<td>quadrangularly shaped anechoic pleural effusion, limited by the pleural line, lung line and shadows of the ribs</td>
</tr>
<tr>
<td>sinusoid sign</td>
<td>sinusoid movement of the lung line toward the pleural line on inspiration noted on M-mode</td>
</tr>
<tr>
<td>fractal sign</td>
<td>irregular border between consolidated and aerated lung in case of non-translobar consolidation</td>
</tr>
<tr>
<td>tissue-like sign</td>
<td>spleen-like image of the lungs in case of translobar consolidation</td>
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</table>
antero-posteriorly during the cardiac cycle, with convex configuration toward the right atrium (RA) in mid- to end-systole and in early-diastole, whereas flat or convex toward the left atrium (LA) in mid- to end-diastole and early systole. (20). With its membranous structure, it is highly dependent on interatrial pressure gradient (IAPG), supported by the findings of limited IAS motion in LA and RA loading situations (20). Mitral stenosis with large left-to-right IAPG was found to be associated with decreased IAS motion throughout the cardiac cycle, with displacement of the IAS towards the RA, while pulmonary hypertension, with increased right-to-left IAPG, was associated with IAS displacement to the left (20). The association between IAS motion and IAPG was further supported by the study in mechanically ventilated patients where IAS was curved towards RA during atrial contraction in end-diastole and in end-systole, but had variable shape in mid-systole depending on the PAWP (21). Mid-systolic reversal, the bowing of the IAS towards LA, was observed during a brief period of passive expiration in patients with a PAWP ≤ 15 mmHg, explained by the systemic venous inflow to the RA exceeding the pulmonary venous inflow to the LA. Mid-systolic reversal, observed during passive expiration as well as positive airway pressure inspiration, pointed towards very low PAWP (≤ 10 mmHg). When the PAWP exceeded 15 mmHg, IAS remained bowed to the right and mid-systolic reversal was absent (21). Similarly, the shape and motion of IAS were found as predictors of change in PAWP in patients undergoing cardiac surgery with marked mid-systolic IAS movement associated with normal- to-low PAWP, mid-systolic reversal associated with normal PAWP and fixed curvature of IAS bowed to the right during the whole cardiac cycle associated with a normal-to-high PAWP (19). Haji et al. found that the fixed curvature of IAS was the best predictor of raised PAWP, when PAWP was ≥ 17 mmHg even in ventilated and anesthetized patients, where Doppler assessment of LAP poorly correlated with PAWP (19). Finally, Masai et al. quantified the IAS motion in AF patients and showed that the amplitude of IAS motion was associated with increased LAP in sinus rhythm and proposed IAS motion as a novel predictor of LAP in AF patients (22).

In the reported studies, transoesophageal echocardiography was used to establish the correlation between shape and motion of IAS and invasive measurement of PAWP. However, in the emergency setting, IAS can be easily viewed by transthoracic echocardiography through any of the available cardiac acoustic windows. Echocardiographic imaging of IAS shape and motion in case of LA and RA loading states are provided in the Illustration 1, Clip 1, Illustration 2 and Clip 2. The absence of echocardiographic examination in the BLUE protocol was argued by Lichtenstein et al. based on the fact that LUS provides a direct approach to ARF, whereas echocardiography gives indirect arguments (8). Moreover, LUS is claimed to be mastered with far more ease and less time consumption than echocardiography (15). However, the authors suggested that at least a simple cardiac sonography usually follows BLUE protocol in practice (8). The idea of combining LUS with basic echocardiography in diagnosing of acute deterioration of heart failure (ADHF) was already proposed by Russel et al. (23). Previous studies found LUS to be highly sensitive for diagnosing ADHF, but lacking specificity as diffuse B-lines can be seen in many other conditions. By adding echocardiography to LUS, the ADHF was diagnosed with 100% specificity (23).

Modification of the BLUE protocol has already been proposed by Khosla (24). He suggested diaphragm assessment as an addition to the BLUE protocol arguing that the current protocol does not enable diagnosis of diaphragm paralysis as an underlying pathology in ARF (24). The contra-argument from Lichtenstein et al. was, however, that the protocol should be designed as a simple tool to serve a wide

Figure 1. Standard placement of the ultrasound probe in the BLUE protocol. Upper BLUE point and Lower BLUE point (a). PLAPS point (b).
variety of physicians and address the most common causes of ARF (25).

With that in mind, based on the current knowledge on IAS shape and motion affecting hemodynamic status in critically ill, we propose IAS shape and motion assessment as an addition to the conventional BLUE protocol (Figure 2). The assessment of LAP according to IAS shape and motion is a simple, non-invasive diagnostic method that could more accurately differentiate between the common states predominantly loading the LA or the RA with shifting of the IAS to the right in pulmonary oedema and left-sided shifting in pulmonary embolism. The modified version of the BLUE protocol is presented in the following scheme (Figure 3).

CONCLUSION

No ideal protocol exists just yet that would be as easy as possible to learn, to practice, to interpret, would be performed in just a couple of minutes and would master all the possible pathologies underlying ARF. Aiming to improve the accuracy of the BLUE protocol, we propose the simple, non-invasive echocardiographic assessment of IAS shape and motion as an upgrade, providing additional information of the loading of LA and RA, thus distinguishing the most common causes of ARF.

REFERENCES


